REPORT 0194 - 5

AN IMPROVED MODEL FOR THE ESTIMATION OF TRIP LENGTH FREQUENCY DISTRIBUTIONS

FAST

FLEXIBLE ABBREVIATED STUDY TECHNIQUES
FOR SKETCH PLANNING AND SUBAREA FOCUSING

STATE DEPARTMENT
OF HIGHWAYS AND
PUBLIC TRANSPORTATION

TTI

TEXAS TRANSPORTATION INSTITUTE

TEXAS A&M UNIVERSITY

AN IMPROVED MODEL FOR THE ESTIMATION OF TRIP LENGTH FREQUENCY DISTRIBUTIONS

Principal Authors

J. D. Benson
Study Supervisor

and

M. F. Teniente
Research Associate

Contributing Authors

Vergil G. Stover
Research Engineer

and

Wiley D. Cunagin
Research Associate

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Flexible Abbreviated Study Techniques (FAST) Report Series

This report is one of a series of reports which documents the development and evaluation of the Flexible Abbreviated Study Techniques (FAST). FAST provides cost-effective analytical techniques for sketch planning and subarea focusing.

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INTRODUCTION

Dimensioning the Problem

A procedure for estimating trip length frequency distributions (11) was developed and implemented under Study 2-10-74-17. This procedure has proven to be a very valuable tool for the analyst in performing the urban transportation studies in Texas. With its extensive usage, the procedure has proven to have two significant deficiencies which warranted immediate attention. The following briefly describes the problems encountered and the proposed approach for overcoming these deficiencies.

In applications involving larger urban areas, the original procedure tended to estimate too few trips at the longer separations. For example, the application of the procedure in the Houston-Galveston Regional Transportation Study (HGRTS) would yield almost no trips longer than 60 minutes while it is reasonable to expect a significant number of trips between 60 and 90 minutes. In essence, the mathematical function used in the original procedure decays far too rapidly at longer separations.

A more severe deficiency can be observed relative to the left-hand tail of the estimated frequency distributions. The current estimation procedure clearly tends to underestimate the trips at the shorter separations. Tables 1-4 summarizes a comparison of the estimated number of trips of three minutes or less versus the observed number of those trips from O-D surveys for a number of urban areas in Texas. Again, the problem is most severe for the larger urban areas (e.g., Dallas-Fort Worth, El Paso, and San Antonio). Similar results were observed in a comparison

TABLE 1

COMPARISON OF HOME-BASED WORK TRIPS

Urban Area	Average Trip Length	Percent Trips In First Three Minutes		
		Percent Observed From O-D Survey	Percent Estimated By Trip Length Frequency Program *	Percent Error
Abilene (1965)	6.213	20.16	20.972	+ 4.028
Amarillo (1964)	10.080	9.50	6.462	-31.979
Austin (1962)	9.457	8.09	7.653	- 5.402
Brownsville (1970)	6.530	20.81	18.808	- 9.620
Bryan-College Station (1970)	7.104	21.96	15.523	-29.312
Dallas-Fort Worth (1964)	14.142	7.03	2.504	-64.381
El Paso (1970)	12.937	9.37	3.238	-65.443
Harlingen-San Benito (1965)	5.723	32.62	24.939	-23.547
JORTS (1963)	12.508	13.40	3.565	-73.396
Laredo (1964)	4.849	34.91	34.425	- 1.389
Lubbock (1964)	8.707	9.68	9.502	- 1.839
McAllen-Pharr (1967)	5.144	34.80	30.824	-11.425
San Angelo (1964)	6.051	20.79	22.259	+ 7.066
San Antonio (1969)	13.518	7.28	2.855	-60.783
Sherman-Denison (1968)	7.387	24.40	14.166	-41.943
Texarkana (1965)	6.025	22.40	22.406	+ 0.027
Tyler (1964)	6.536	20.10	18.807	- 6.433
Victoria (1970)	5.751	29.11	24.689	-15.187
Waco (1964)	9.705	10.58	7.145	-32.467
Wichita Falls (1964)	9.140	10.61	8.372	-21.093

* One-parameter gamma model (11).

TABLE 2

COMPARISON OF HOME-BASED NONWORK TRIPS

Urban Area	Average Trip Length	Percent Trips In First Three Minutes		
		Percent Observed From O-D Survey	Percent Estimated By Trip Length Frequency Program*	Percent Error
Abilene (1965)	4.634	43.64	39.793	- 8.815
Amarillo (1964)	7.157	23.47	18.633	-20.609
Austin (1962)	6.798	22.63	20.586	- 9.032
Brownsville (1970)	5.630	29.18	29.024	- 0.535
Bryan-College Station (1970)	5.668	32.07	28.688	-10.546
Dallas-Fort Worth (1964)	7.741	26.29	15.736	-40.145
El Paso (1970)	9.294	22.85	10.857	-52.486
Harlingen-San Benito (1965)	4.693	46.53	39.036	-16.106
JORTS (1963)	7.324	32.50	17.805	-45.215
Laredo (1964)	4.163	44.87	46.554	+ 3.753
Lubbock (1964)	6.429	23.15	22.878	- 1.175
McAllen-Pharr (1967)	4.432	44.30	42.527	- 4.002
San Angelo (1964)	4.638	41.00	39.782	- 2.971
San Antonio (1969)	8.715	23.24	12.463	-46.373
Sherman-Denison (1968)	4.828	42.70	37.366	-12.492
Texarkana (1965)	4.776	39.80	38.006	- 4.508
Tyler (1964)	4.921	36.90	36.273	- 1.699
Victoria (1970)	4.801	42.81	37.694	-11.950
Waco (1964)	6.901	28.40	19.999	-25.581
Wichita Falls (1964)	6.290	27.56	23.818	-13.578

* One-parameter gamma model (11).

TABLE 3

COMPARISON OF NONHOME-BASED TRIPS

Urban Area	Average Trip Length	Percent Trips In First Three Minutes		
		Percent Observed From O-D Survey	Percent Estimated By Trip Length Frequency Program*	Percent Error
Abilene (1965)	4.489	41.27	43.387	+ 5.130
Amarillo (1964)	6.729	26.39	23.711	-10.152
Austin (1962)	6.329	29.75	26.218	-11.872
Brownsville (1970)	4.819	37.85	39.442	+ 4.206
Bryan-College Station (1970)	5.153	36.35	35.890	- 1.265
Dallas-Fort Worth (1964)	8.979	22.19	14.263	-35.723
El Paso (1970)	8.814	23.94	14.761	-38.342
Harlingen-San Benito (1965)	3.991	52.58	50.254	- 4.424
JORTS (1963)	7.236	33.60	20.975	-37.574
Laredo (1964)	3.908	50.06	51.537	+ 2.950
Lubbock (1964)	6.641	21.85	24.276	+11.103
McAllen-Pharr (1967)	3.898	50.30	51.707	+ 2.797
San Angelo (1964)	4.610	39.65	41.968	+ 5.846
San Antonio (1969)	9.576	20.26	12.643	-37.596
Sherman-Denison (1968)	4.608	50.50	41.916	-16.998
Texarkana (1965)	4.343	45.30	45.287	- 0.029
Tyler (1964)	4.543	42.60	42.715	+ 0.270
Victoria (1970)	4.037	51.84	49.570	- 4.379
Waco (1964)	6.905	29.60	22.710	-23.277
Wichita Falls (1964)	5.946	33.57	28.952	-13.756

* One-parameter gamma model (11).

TABLE 4

COMPARISON OF TRUCK-TAXI TRIPS

Urban Area	Average Trip Length	Percent Trips In First Three Minutes		
		Percent Observed From O-D Survey	Percent Estimated By Trip Length Frequency Program*	Percent Error
Abilene (1965)	5.007	41.36	41.410	+ 0.121
Amarillo (1964)	7.564	27.72	25.404	- 8.355
Austin (1962)	7.194	27.72	27.094	- 2.258
Brownsville (1970)	5.829	34.78	34.962	+ 0.523
Bryan-College Station (1970)	6.259	40.75	32.129	-21.156
Dallas-Fort Worth (1964)	9.503	26.98	18.768	-30.437
El Paso (1970)	8.403	34.57	22.149	-35.930
Harlingen-San Benito (1965)	5.503	41.02	37.349	- 8.949
JORTS (1963)	9.815	28.60	17.954	-37.224
Laredo (1964)	3.945	50.13	52.773	+ 5.272
Lubbock (1964)	6.904	26.19	28.604	+ 9.217
McAllen-Pharr (1967)	4.813	42.10	43.253	+ 2.739
San Angelo (1964)	5.002	37.09	41.743	+12.545
San Antonio (1969)	9.899	23.34	17.756	-23.925
Sherman-Denison (1968)	5.121	43.50	40.400	- 7.126
Texarkana (1965)	4.853	40.90	42.923	+ 4.946
Tyler (1964)	4.989	41.60	41.658	+ 0.139
Victoria (1970)	5.033	41.60	41.181	- 1.007
Waco (1964)	7.948	28.52	23.832	-16.438
Wichita Falls (1964)	6.063	35.01	33.381	- 4.653

* One-parameter gamma model (11).

of the estimated versus observed trips of five minutes or less trip length.

The principal benefit of an accurate trip length frequency estimation procedure is that is has allowed reduced data requirements for urban transportation studies. Previous research (1) has shown that a home interview survey of approximately 600 dwelling units will provide a reliable estimate of the mean trip length but a poor estimate of the frequency distribution. Given the mean trip length, the procedure can be used to estimate the frequency distribution. The trip length frequency distribution is, of course, of great importance since it is used as an objective function in the trip distribution process for both the Texas model and the disaggregate trip distribution model for sketch planning and subarea focusing (i.e., the Atomistic model).

Literature Review

An extensive research effort on factors affecting trip length, conducted by Voorhees and Associates, developed a theoretical trip length frequency distribution (TLFD) utilizing the gamma distribution, the parameters of which were estimated using the maximum likelihood method of fit (15). The principal findings of the Voorhees study that are pertinent to the research reported herein are:

a. Population and network speed were found to account for much of the variation in the work, social-recreation, and nonhome-based trip length.

b. The analysis of the relationship between trip length, city size and network speed found that the duration of social-recreation trips did not increase as fast as the duration of work trips.

c. The average duration of truck trips and average duration of shopping trips were found to be correlated.

d. Simulation studies showed that the average trip duration increased with population and decreased with both increasing travel speed and concentration of activity at the area's center.

A more recent research effort, conducted by Pearson, Stover, and Benson (11) of the Texas Transportation Institute, used a direct approach in the estimation of the parameter values of the gamma distribution. The trip length frequency data was non-dimensionalized by the average trip length; and, the parameter values were derived directly. The calibration tests revealed that a close fit between the estimated and observed trip length distributions was achieved when both the shape and scale parameters of the gamma distribution had the same, or very nearly the same, value. Therefore, a single parameter value that varied by trip purpose was adopted. An estimating equation also was developed for the maximum separation at which trips were expected to occur for the different trip purposes.

Though other probability distributions are similar to the gamma distribution, the Voorhees study (15) found that the gamma distribution gave the best results in fitting TLFD data. The previous TTI study (11) found that the Wiebull and gamma distributions produced comparable results and concluded that the choice between the two was arbitrary.

STUDY DESIGN

General Approach

The approach followed in the present research utilized the gamma distribution to estimate the trip length frequency distribution. Like the Voorhees study (15), different values are estimated for the two parameters using the maximum likelihood of fit method. Prior TTI research (11) had set both parameters of the gamma distribution equal to the same value. The maximum separation at which trips could be expected to occur was calculated using the algorithm presented in this previous TTI research. The procedure presented herein determines the theoretical TLFD using the maximum likelihood method of fit based on the average trip length and maximum separation.

Data Base

Data from the urban transportation studies conducted in Texas were utilized as the data base for this research. The 24 urban areas in Texas are predominantly small- to medium-sized cities; Dallas-Fort Worth, Houston, San Antonio, Corpus Christi, and El Paso constitute the large urban areas. Observed TLFD was available for 18 of the urban transportation studies conducted in Texas between 1960 and 1970. Of these, 13 were used to initially develop and calibrate the models; data from the other five urban areas were utilized for model evaluation and verification. Data from all 18 studies were then used in the development of the final calibrated models.

Methodology

Application of the maximum likelihood principle to produce a theoretical trip length frequency distribution has shown that the values of the two parameters of the gamma function are best estimated from the difference between the natural logarithms of the arithmetic mean and the geometric mean of the trip lengths. (11). Since the arithmetic mean is much easier to calcuate than the geometric mean, a major portion of this research effort was to determine the geometric mean as a function of the arithmetic mean.

It has been shown (14) that for a given probability distribution, the geometric mean is smaller than the arithmetic mean. The fitting of the data points was accomplished by means of a manual trial and error approach; the parameter estimating equations were determined for each trip purpose.

Measures For Evaluation Of Results

The thrust of this research was to improve the formulation of the theoretical TLFD to produce better results at either tail. For evaluation and discussion, the results were grouped by trip purpose and analyzed as follows.

a. The absolute difference between the theoretical estimate and the observed average trip length was determined for both the one-parameter and two-parameter gamma distributions. An absolute difference of less than three percent was accepted as being not significant.

b. The percentage of trips of three minutes or less separation for both theoretical distributions was compared to the observed data. The comparison based on the first three minutes of separation is consistent with the small zone size characteristic of the several Texas urban transportation studies.

c. The percentage of trips at the longer separations of the distribution were compared to the observed data; the right-hand tail of the TLFD was defined as the separations longer than 0.60 times the maximum separation.

d. The following commonly used statistical measures were computed: the coefficient of correlation (R), the coefficient of determination (R^2) and the root mean square error (RMS) for both gamma distributions.

MODEL CALIBRATION AND EVALUATION

Introduction

A two-parameter gamma model was calibrated for each of the four internal trip purposes (i.e., home-based work vehicle trips, home-based nonwork vehicle trips, nonhome-based vehicle trips, and truck-taxi vehicle trips) using a selected subset of available observed trip length frequency data from urban areas in Texas. The calibrated model was applied to each of the urban areas in Texas for which observed trip length frequency data were available. For purposes of comparison, the previously calibrated one-parameter model (11) was also applied to each of the urban areas.

As previously noted, the evaluation and comparisons focus on the following for each of the four trip purposes:

1. The ability of the models to reproduce the desired average trip lengths (i.e., the basic input to the model).
2. Comparison of the observed percentage of short trips (i.e., intrazonal trips and interzonal trips with spatial separations of three network minutes or less) with the estimates yielded by each of the calibrated models.
3. Comparison of the observed percentage of longer trips (i.e., trips with spatial separation greater than 0.6 times the observed maximum trip length) with the estimates yielded by each of the calibrated models.
4. Various commonly used statistical measures (i.e., R, R^2, and RMS error) were also employed in the evaluation and comparison of the two calibrated models for each trip purpose.

Due to the large amount of data involved in the presentation of the model calibration and evaluation (i.e., four graphs and 16 tables), the tables and graphs of the results have been placed in Appendices A and B, and are referenced in the text.

Estimating the Geometric Mean

The basic form of the estimating equations of the geometric mean was determined to be a natural log function for all four trip purposes. The coefficients, 'a' and 'b', were found to vary by trip purpose; the general forms of the models are:

Home-based work geometric mean ------------- = $(\ln X)(X^a + b)$

Home-based nonwork geometric mean ---------- = $(\ln X)(aX + b + e^{-X})$

Nonhome-base geometric mean ---------------- = $(\ln X)(aX + b + e^{-X})$

Truck-taxi geometric mean ------------------ = $(\ln X)(aX + b + e^{-X})$

Where X = average trip length (arithmetic mean)

The estimating function for the home-based work geometric mean reflects the longer average trip length peculiar to the trip purpose. Likewise, the similarity between the home-based nonwork and nonhome-based geometric mean functions reflect the established correlation between both trip purposes. The graphs of the estimating functions of the geometric mean by trip purpose along the observed data points are presented in Appendix A.

Home-based Work

The estimated geometric mean produced reasonably accurate results for home-based work trips. Only two urban areas, Lubbock and Wichita Falls, had differences of over 0.10 minute in the average trip length (slightly more than 1.4 percent of the observed average trip length). The difference between the estimated and observed average trip length was less than 1.0 percent for the other urban areas (see Appendix B, Table 1).

The two-parameter estimate resulted in substantially better results for the percentage of trips at the first three minutes of separation for the larger urban areas than the one-parameter estimate (see Appendix B, Table 2). However, it produced more than the observed percentage of trips at the first three minutes of separation for the Lubbock and Austin urban areas; the one-parameter estimate resulted in better results for these two urban areas. This is due to the fact that the two-parameter model underestimated the geometric mean for these urban areas. However, the comparison of the urban area characteristics did not reveal differences that would explain this result for Lubbock and Austin. The results indicate that the TLFD (at the shorter separations) is sensitive to the ratio of the arithmetic and geometric means.

The one-parameter estimate minimized the difference between the observed and theoretical average trip length for the larger urban areas. As a result, the percentage of trips at the first three minutes was underestimated for the large urban areas. The two-parameter gamma resulted in a better estimate of the percentage of trips at the first three minutes of separation. However, it also results in a slightly greater difference between the theoretical and observed average trip lengths. The largest percent difference in the average trip length was 1.45 percent of the observed. The differences are well within the three percent difference commonly accepted in trip distribution model calibration and is was concluded that the difference between two-parameter estimate and the observed is not significant. A consistent relationship between the geometric mean estimate and the average trip length difference was not observed.

The analysis of differences in the right-hand tail (longer separations) of the TLFD indicate a general improvement for the large urban areas (see Appendix B, Table 3). However, the two-parameter gamma estimate did not result in a consistent improvement at the longer separations for the smaller urban areas. As shown by the data in Appendix B, Table 4, the statistical measures indicate a decrease in the RMS error with an improvement in the percentage of trips at the first three minutes (e.g., the large urban areas). It was concluded that the two-parameter estimate was significantly better than the one-parameter estimate for home-based work trips.

Home-based Nonwork

The two-parameter estimate produced smaller differences between the estimated and observed average trip length for home-based nonwork trips for all except the smaller urban areas (see Appendix B, Table 5). Differences in the average trip length for the larger areas were somewhat greater than those resulting from the one-parameter gamma estimate.

However, as indicated in Appendix B, Table 6, the percentage of trips at separations of three minutes or less was substantially improved for the larger urban areas. Again, Lubbock and Austin were the only two cases where the estimate of the percentage of trips at the first three minutes was larger than the observed. However, the differences (less than two percent) are not of practical significance. The one-parameter estimate produced good results for both the Lubbock and Austin urban areas.

A consistent improvement in the percentage of trips in the right-hand tail of the distribution as well as in the RMS error values was observed for the large urban areas with the two-parameter estimate (see Appendix B, Tables 7 and 8). The increase or decrease in the RMS error reflects the deterioriation or improvement of the percentage of trips at the first three minutes or less of separation. Again, the two-parameter model was judged superior to the one-parameter model for large urban areas and essentially equivalent for the smaller urban areas.

Nonehome Based

The difference in the average trip length resulting from the two-parameter estimate was found to increase for the large urban areas (see Appendix B, Table 9). However, the difference between the two-parameter estimate and the observed values was less than one percent of the observed value. Less Difference in the average trip length for the smaller urban areas was obtained with the two-parameter than with the one-parameter estimate. For the large urban areas, the two-parameter estimate showed improvement over the one-parameter estimate in the percentage of trips at separations of three minutes or less, in the right-hand tail of the distribution, and in the RMS error values (see Appendix B, Tables 10-12). Again, the two-parameter model was judged superior for larger urban areas and essentially equivalent for the smaller urban areas.

Truck and Taxi

The theoretical results obtained with the two-parameter gamma distribution demonstrated an improvement in the average trip length estimates compared to the one-parameter estimate (see Appendix B, Table 13). The largest difference was indicated for Dallas-Fort Worth with a percentage difference of near 1.4 percent. The improvement in the percentage of trips at the first three minutes was not as distinct as observed for the other trip purposes (see Appendix B, Table 14). The analysis of differences in the right-hand tail of the TLFD indicate a general improvement for the large urban areas (see Appendix B, Table 15). The RMS error was noticeably increased compared to the one-parameter gamma estimate (see Appendix B, Table 16). The largest RMS error value, 2.6, resulted for the Laredo urban area. Both models were judged to be adequate for the estimation of truck-taxi length frequency distributions.

Calibrated Models

The one-parameter gamma distribution was obtained by a direct estimation of the parameter using nondimensionalized data. The following models are the general gamma distribution with the final calibrated parameter values substituted and the equation reduced:

Home-based Work	$f(t)$	=	$26.15\ t^{2.57}\ e^{-3.57}$
Home-based Nonwork	$f(t)$	=	$12.42\ t^{1.929}\ e^{-2.929}$
Nonhome-based	$f(t)$	=	$7.43\ t^{1.5}\ e^{-2.5}$
Truck-Taxi	$f(t)$	=	$2.89\ t^{0.75}\ e^{-1.75}$

The maximum separation at which trips can occur is estimated by the models listed below:

Home-based Work	Y	=	0.783 X
Home-based Nonwork	Y	=	0.767 X
Nonhome-based	Y	=	0.880 X
Truck-Taxi	Y	=	0.824 X

Where: X = Maximum separation possible

Y = Estimate of the maximum separation at which an interchange of trips will occur.

The two parameter gamma distribution using the maximum likelihood method of fit is obtained by the following computational procedure. The maximum likelihood estimate is that which maximizes the likelihood function for a given set of data. The generalized gamma function is expressed:

$$f(t) = \frac{\beta^{\alpha}}{\Gamma(\alpha)} t^{\alpha-1} e^{-\beta t}$$

Where: t = time

$f(t)$ = relative density of occurence of trips taking time t

α = shape parameter

β = scale parameter

e = 2.71828

$\Gamma(\alpha)$ = $(\alpha-1)!$

The likelihood function in its logarithmic form yields the condition for its maximum value

$$\ln \alpha - \frac{d}{d\alpha}\left[\ln \Gamma(\alpha)\right] = \ln \mu - \ln G$$

Where μ = arithmetic mean of TLFD

G = geometric mean of TLFD

Using the values shown in Table 5, developed by Greenwood and Durand (5), the following steps may be followed to obtain estimates for the parameters α and β (16):

1. Determine the arithmetic, μ, mean trip length of the urban area.

2. Determine the geometric, G, mean trip length using the final calibrated models:

   Home-based Work geometric mean = $\ln(\mu)(\sqrt{\mu} + 0.46)$

   Home-based Nonwork geometric mean = $\ln(\mu)(0.11\mu + 2.1 + e^{-\mu})$

   Nonhome-based geometric mean = $\ln(\mu)(0.11\mu + 2.0 + e^{-\mu})$

   Truck-Taxi geometric mean = $\ln(\mu)(0.085\mu + 2.1 + e^{-\mu})$

3. Compute $\gamma = \ln\mu - \ln G$

4. Using Table 5, find $\gamma\alpha$ and solve for α using the relationship $\alpha = \gamma\alpha/\gamma$

5. Solve for β using the relationship, $\beta = \alpha/\mu$

TABLE 5: TABLE FOR ESTIMATING PARAMETERS OF GAMMA DISTRIBUTION

Value of γ	Value of $\gamma\alpha$	Value of γ	Value of $\gamma\alpha$	Value of γ	Value of $\gamma\alpha$	Value of γ	Value of $\gamma\alpha$
0.10	0.5161	0.23	0.5352	0.36	0.5523	0.49	0.5677
0.11	0.5176	0.24	0.5366	0.37	0.5536	0.50	0.5689
0.12	0.5192	0.25	0.5380	0.38	0.5548	0.51	0.5700
0.13	0.5207	0.26	0.5393	0.39	0.5560	0.52	0.5711
0.14	0.5222	0.27	0.5407	0.40	0.5573	0.53	0.5722
0.15	0.5237	0.28	0.5420	0.41	0.5585	0.54	0.5733
0.16	0.5252	0.29	0.5433	0.42	0.5597	0.55	0.5743
0.17	0.5266	0.30	0.5447	0.43	0.5608	0.56	0.5754
0.18	0.5281	0.31	0.5460	0.44	0.5620	0.57	0.5765
0.19	0.5295	0.32	0.5473	0.45	0.5632	0.58	0.5775
0.20	0.5310	0.33	0.5486	0.46	0.5643	0.59	0.5786
0.21	0.5324	0.34	0.5498	0.47	0.5655	0.60	0.5796
0.22	0.5338	0.35	0.5511	0.48	0.5666	0.61	0.5806

Source: Reference 5.

SUMMARY AND CONCLUSIONS

The major problem with the original TTI model for the estimation of trip length frequency distributions (i.e., the one-parameter gamma model described in TTI Research Report 17-1) was its tendency to substantially underestimate the portion of trips at shorter separations for the larger urban areas in Texas. While less severe, the same problem also existed in the right-hand tail estimate of frequency distribution. In other words, the previously calibrated one-parameter gamma model tended to decay too rapidly in the tails when estimating the frequency distributions for the larger urban areas.

An improved model (i.e., a two-parameter gamma model) was calibrated for application in Texas cities. The maximum likelihood method was employed in the model calibration. In the calibration phase, a set of models was developed (i.e., one model for each trip purpose) to estimate the geometric mean given the arithmetic mean of the desired frequency distribution.

The calibrated two-parameter gamma model yields substantially better estimates of the portion of trips at the shorter separations for the larger urban areas in Texas. Both the one-parameter and two-parameter gamma models were found to provide reasonable estimates of the trips at shorter separations for the smaller urban areas in Texas.

The two-parameter gamma model was found to provide only marginal improvements in the right-hand tail of estimates of the frequency distributions for the larger urban areas. As a result, an option has been provided for the analyst to impose a constraint which specifies the minimum value which the right-hand tail should asymptotically approach. Since this optional constraint would affect only a very small portion of the total trips, it was judged to be unnecessary to recalibrate the models to reflect the constraint. Again, both the one-parameter and two-parameter gamma models were judged to yield good estimates of the portions of trips in the right-hand tail of the frequency distribution for smaller urban areas. Hence, the optional constraint should be principally utilized in conjunction with the larger urban areas in Texas.

The data utilized in this research produced a specific calibration of the two-parameter gamma model for application in urban areas in Texas. The procedure evaluated, however, should be universally applicable. Recalibration using data for different regions may be desirable prior to utilization of the model in areas outside Texas.

The trip length frequency distribution model is a key element which has facilitated reduced data requirements for urban transportation studies. The trip length frequency distribution model is employed in both synthetic studies and studies utilizing small sample home interview survey data. A good estimate of trip length frequency distribution is, of course, of great importance since it is used as an objective function in the trip distribution model for sketch planning or subarea focusing (i.e., the Atomistic model). Having identified the deficiencies in the existing model (i.e., the one-parameter gamma model) an improved model was necessary to facilitate the continued application of synthetic study techniques and small sample survey techniques in conjunction with the large urban area studies in Texas. Application of the synthetic study

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techniques and the small sample survey techniques have yielded substantial cost savings for these studies. The improved trip length frequency distribution model should enhance the continued accrual of these cost savings to the State of Texas.

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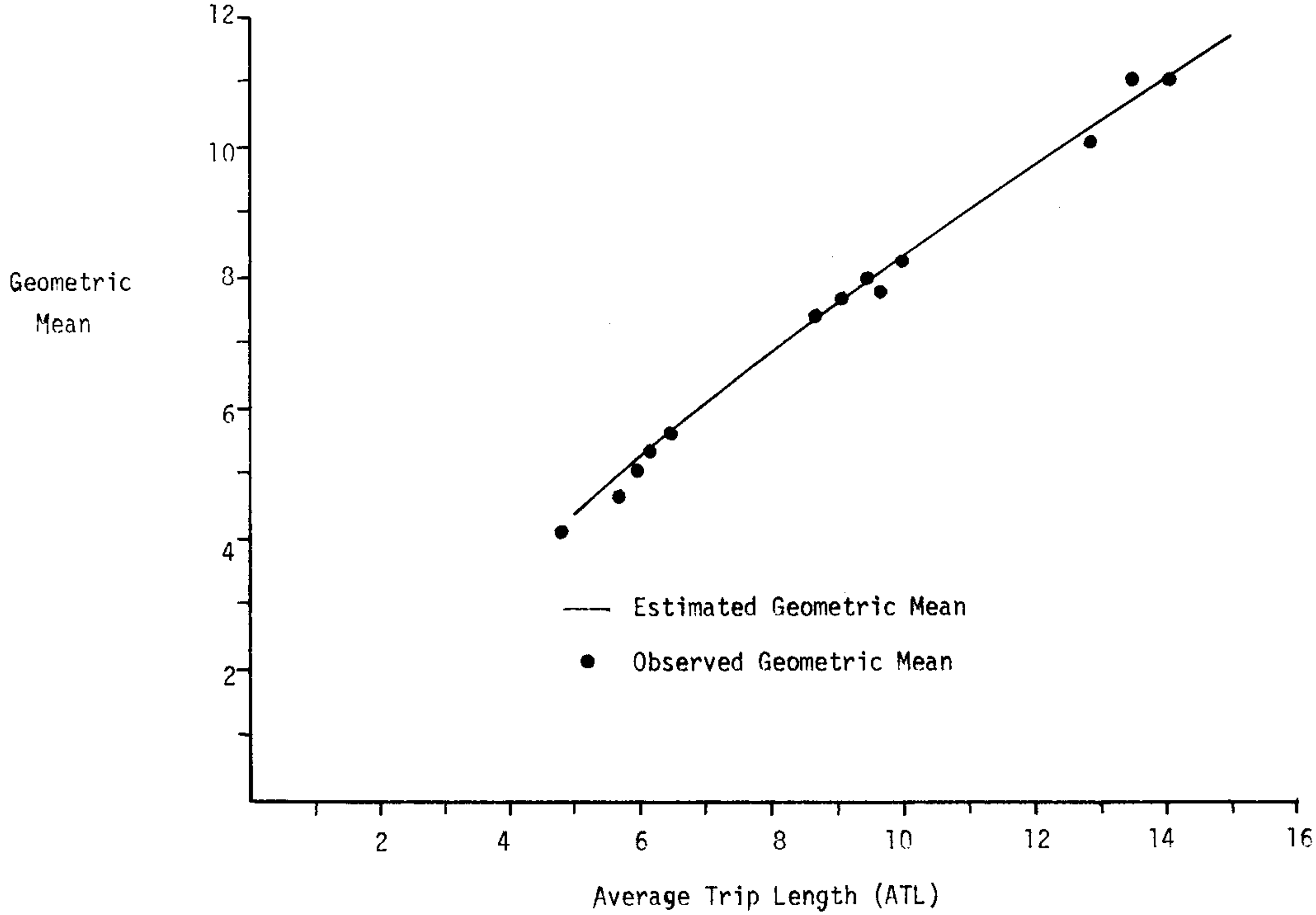
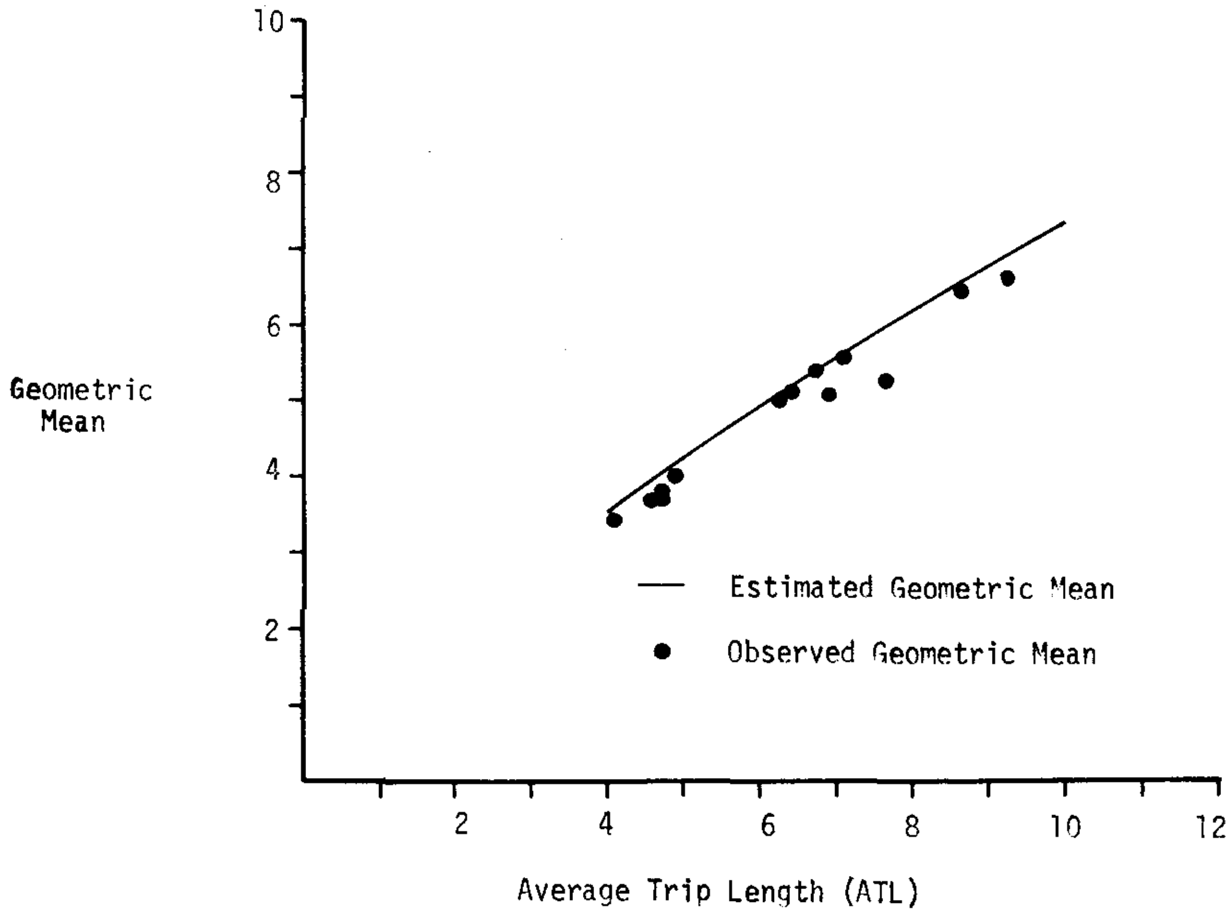
Appendix A

Graphs of the Estimating Functions of the Geometric Mean by Trip Purpose



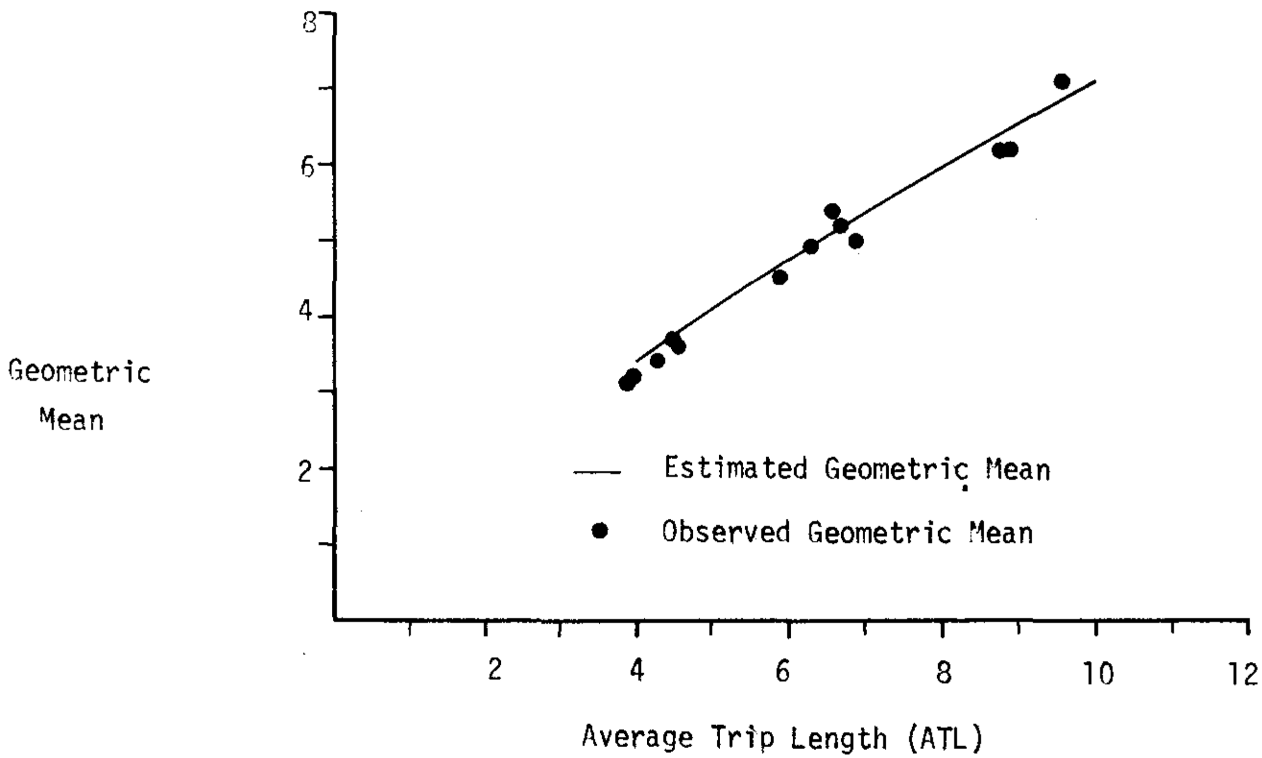
Home Based Work Geometric Mean=(ln ATL)($\sqrt{ATL}$ + 0.46)

Figure 1



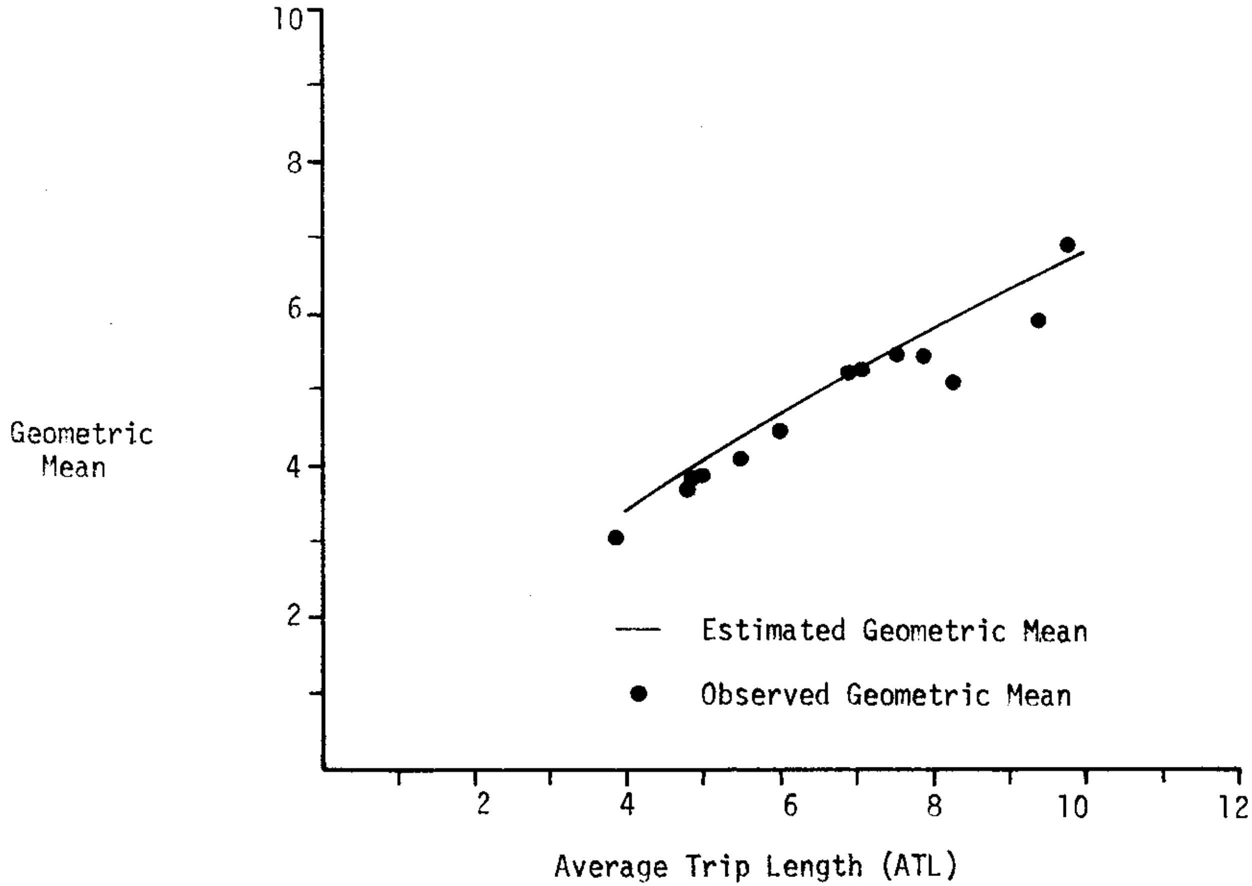
Home Based Non Work Geometric Mean $= (\ln ATL)(0.11ATL + 2.1 + e^{-ATL})$

Figure 2



Non Home Based Geometric Mean $= (\ln ATL)(0.11ATL + 2.0 + e^{-ATL})$

Figure 3



Truck and Taxi Geometric Mean $= (\ln ATL)(0.085ATL + 2.1 + e^{-ATL})$

Figure 4

Appendix B

Results from Application of Two-Parameter Gamma Model and Comparative Results From One-Parameter Gamma Model

TABLE 1

HOME BASED WORK

AVERAGE TRIP LENGTH (ATL) DIFFERENCE[1]

	Urban Area[2]	Observed ATL	One-Parameter Gamma ATL Difference	Two-Parameter[3] Gamma ATL Difference
1.	Laredo	4.849	0.027	.025
2.	Harlingen-San Benito	5.723	0.003	.003
3.	Texarkana	6.025	0.013	.011
4.	Abilene	6.213	0.003	.005
5.	Tyler	6.536	0.082	.076
6.	Lubbock	8.707	0.086	.126
7.	Wichita Falls	9.140	0.075	.123
8.	Austin	9.457	0.021	.044
9.	Waco	9.705	0.004	.010
10.	Amarillo	10.080	0.004	.017
11.	El Paso	12.937	0.001	.006
12.	San Antonio	13.518	0.003	.098
13.	Dallas-Fort Worth	14.142	0.000	.009
14.	McAllen-Pharr	5.144	0.005	.007
15.	Victoria	5.751	0.002	.008
16.	San Angelo	6.051	0.065	.058
17.	Brownsville	6.530	0.005	.006
18.	Bryan-College Station	7.104	0.001	.002

[1] ATL DIFFERENCE = Observed ATL – Estimated ATL.

[2] Urban Areas 1-13 used for calibration.

[3] Geometric Mean = $(\ln ATL)(\sqrt{ATL} + 0.46)$

TABLE 2

HOME BASED WORK

SUM OF PERCENTAGE TRIPS $\leq$ 3-MINUTES OF SEPARATION

	Urban Area[1]	Observed Data Percent	One-Parameter Gamma Percent	Two-Parameter[2] Gamma Percent
1.	Laredo	34.91	34.43	34.14
2.	Harlingen-San Benito	32.62	24.94	24.19
3.	Texarkana	22.40	22.41	21.74
4.	Abilene	20.16	20.97	20.41
5.	Tyler	20.10	18.81	18.49
6.	Lubbock	9.68	9.50	11.24
7.	Wichita Falls	10.61	8.37	10.50
8.	Austin	8.09	7.65	10.00
9.	Waco	10.58	7.15	9.67
10.	Amarillo	9.50	6.46	9.26
11.	El Paso	9.37	3.24	7.36
12.	San Antonio	7.28	2.85	7.14
13.	Dallas-Fort Worth	7.03	2.50	6.93
14.	McAllen-Pharr	34.80	30.82	30.24
15.	Victoria	29.11	24.69	23.99
16.	San Angelo	20.79	22.26	21.63
17.	Brownsville	20.81	18.81	18.43
18.	Bryan-College Station	21.96	15.52	15.66

[1] Urban areas 1-13 used for calibration.

[2] Geometric Mean = $(\ln ATL)(\sqrt{ATL} + 0.46)$.

TABLE 3

HOME BASED WORK

PERCENTAGE OF TRIPS IN RIGHT TAIL OF DISTRIBUTION[1]

Urban Area[2]	Observed[3] Maximum Separation	Observed Percent	One-Parameter Gamma Percent	Two-Parameter[4] Gamma Percent
1. Laredo	17	2.40	3.19	2.95
2. Harlingen-San Benito	26	1.67	0.48	0.41
3. Texarkana	22	2.37	2.66	2.45
4. Abilene	25	1.27	1.37	1.27
5. Tyler	20	6.28	5.92	5.49
6. Lubbock	25	6.15	8.06	8.81
7. Wichita Falls	29	6.47	5.95	6.69
8. Austin	33	3.72	3.19	4.09
9. Waco	46	0.91	0.42	0.72
10. Amarillo	44	3.31	0.97	1.58
11. El Paso	73	0.30	0.09	0.44
12. San Antonio	51	1.96	2.12	4.29
13. Dallas-Fort Worth	95	0.49	0.02	0.16
14. McAllen-Pharr	19	3.86	2.69	2.52
15. Victoria	27	1.52	0.49	0.43
16. San Angelo	18	5.20	6.04	5.64
17. Brownsville	24	7.31	2.80	2.75
18. Bryan-College Station	32	2.95	0.70	0.72

[1] Right tail of distribution = the percentage of trips at and beyond 0.60X observed maximum separation where trips occurred.

[2] Urban areas 1-13 used for calibration.

[3] Observed Maximum Separation - Observed maximum separation when trips occurred.

[4] Geometric Mean = $(\ln ATL)(\sqrt{ATL} + 0.46)$.

TABLE 4

COMPARISON OF HOME BASED WORK THEORETICAL TLFD's
WITH OBSERVED TLFD

Urban Area	Max Sep Obs	Max Sep Est	One Parameter Gamma R	One Parameter Gamma R^2	One Parameter Gamma RMS Error	Two Parameter Gamma** R	Two Parameter Gamma** R^2	Two Parameter Gamma** RMS Error
*Abilene	25	27	0.9929	0.9858	0.58%	0.9923	0.9847	0.59%
*Amarillo	44	42	0.9768	0.9541	0.59%	0.9789	0.9583	0.59%
*Austin	33	33	0.9908	0.9817	0.42%	0.9860	0.9722	0.52%
Brownsville	24	26	0.9635	0.9283	1.18%	0.9572	0.9163	1.34%
Bryan-College Station	32	36	0.9727	0.9461	0.84%	0.9708	0.9425	0.93%
*Dallas-Fort Worth	95	98	0.9618	0.9250	0.46%	0.9858	0.9718	0.28%
*El Paso	73	68	0.9609	0.9233	0.57%	0.9884	0.9769	0.29%
*Harlingen-San Benito	26	24	0.9555	0.9129	1.43%	0.9439	0.8910	1.69%
*Laredo	17	15	0.9763	0.9531	1.36%	0.9728	0.9463	1.49%
*Lubbock	25	25	0.9596	0.9209	0.97%	0.9362	0.8764	1.17%
McAllen-Pharr	19	20	0.9823	0.9649	1.06%	0.9760	0.9526	1.31%
San Angelo	18	17	0.9855	0.9713	0.84%	0.9837	0.9677	0.90%
*San Antonio	51	60	0.9643	0.9299	0.55%	0.9702	0.9414	0.47%
*Texarkana	22	21	0.9784	0.9573	1.01%	0.9736	0.9479	1.17%
*Tyler	20	18	0.9903	0.9807	0.65%	0.9885	0.9771	0.73%
Victoria	27	28	0.9749	0.9505	1.03%	0.9692	0.9393	1.23%
*Waco	46	41	0.9689	0.9387	0.72%	0.9781	0.9568	0.58%
*Wichita Falls	29	27	0.9852	0.9706	0.58%	0.9820	0.9644	0.59%

* Urban areas used for calibration.

Max Sep — the maximum separation at which an interchange of trips may be expected to occur.

Obs - observed data

Est - estimated data

** Geometric Mean = $(\ln ATL)(\sqrt{ATL} + 0.46)$.

TABLE 5

HOME BASED NONWORK

AVERAGE TRIP LENGTH (ATL) DIFFERENCE[1]

	Urban Area[2]	Observed ATL	One-Parameter Gamma ATL Difference	Two-Parameter[3] Gamma ATL Difference
1.	Laredo	4.163	0.007	0.008
2.	Abilene	4.634	0.006	0.002
3.	Harlingen-San Benito	4.693	0.005	0.002
4.	Texarkana	4.776	0.002	0.003
5.	Tyler	4.921	0.012	0.009
6.	Wichita Falls	6.290	0.005	0.006
7.	Lubbock	6.429	0.011	0.015
8.	Austin	6.798	0.000	0.008
9.	Waco	6.901	0.002	0.015
10.	Amarillo	7.157	0.002	0.016
11.	Dallas-Fort Worth	7.741	0.002	0.027
12.	San Antonio	8.715	0.001	0.039
13.	El Paso	9.294	0.001	0.048
14.	McAllen-Pharr	4.432	0.003	0.003
15.	San Angelo	4.638	0.009	0.004
16.	Victoria	4.801	0.005	0.003
17.	Brownsville	5.630	0.000	0.007
18.	Bryan-College Station	5.668	0.004	0.002

[1] ATL Difference = Observed ATL - Estimated ATL.

[2] Urban areas 1-13 used for calibration.

[3] Geometric Mean = $(\ln ATL)(.11ATL + 2.1 + e^{-ATL})$.

TABLE 6

HOME BASED NONWORK

SUM OF PERCENTAGE TRIPS $\leq$ 3-MINUTES OF SEPARATION

Urban Area[1]	Observed Data Percent	One-Parameter Gamma Percent	Two-Parameter[2] Gamma Percent
1. Laredo	44.87	46.55	43.18
2. Abilene	43.64	39.79	36.99
3. Harlingen-San Benito	46.53	39.04	36.36
4. Texarkana	39.80	38.01	35.51
5. Tyler	36.90	36.27	34.15
6. Wichita Falls	27.56	23.82	25.68
7. Lubbock	23.15	22.88	25.13
8. Austin	22.63	20.59	23.76
9. Waco	28.40	19.99	23.42
10. Amarillo	23.47	18.63	22.64
11. Dallas-Fort Worth	26.29	15.74	21.09
12. San Antonio	23.24	12.46	19.11
13. El Paso	22.85	10.86	18.16
14. McAllen-Pharr	44.30	42.53	39.39
15. San Angelo	41.00	39.78	36.93
16. Victoria	42.81	37.69	35.28
17. Brownsville	29.18	29.02	28.99
18. Bryan- College Station	32.07	28.69	28.74

[1] Urban area 1-13 used for calibration.

[2] Geometric Mean = $(\ln ATL)(0.11ATL + 2.1 + e^{-ATL})$.

TABLE 7

HOME BASED NONWORK

PERCENTAGE TRIPS IN RIGHT TAIL OF DISTRIBUTION[1]

	Urban Area[2]	Observed[3] Maximum Separation	Observed Percent	One-Parameter Gamma Percent	Two-Parameter[4] Gamma Percent
1.	Laredo	14	5.36	5.34	3.51
2.	Abilene	24	1.00	0.64	0.22
3.	Harlingen-San Benito	25	1.12	0.16	0.14
4.	Texarkana	21	1.01	0.81	0.58
5.	Tyler	21	1.01	1.08	0.75
6.	Wichita Falls	29	1.73	1.14	1.38
7.	Lubbock	25	2.71	3.79	3.14
8.	Austin	36	0.80	0.31	0.56
9.	Waco	45	0.070	0.13	0.15
10.	Amarillo	51	0.31	0.03	0.07
11.	Dallas-Fort Worth	94	0.24	0.00	0.00
12.	San Antonio	47	1.44	1.08	1.13
13.	El Paso	72	1.18	0.02	0.11
14.	McAllen-Pharr	18	2.39	1.07	0.86
15.	San Angelo	17	3.89	4.23	2.39
16.	Victoria	27	1.08	0.10	0.11
17.	Brownsville	31	0.61	0.11	0.19
18.	Bryan-College Station	36	0.25	0.06	0.06

[1] Right tail of distribution = the percentage of trips at and beyond 0.60 X observed maximum separation where trips occurred.

[2] Urban areas 1-13 used for calibration.

[3] Observed Maximum Separation — observed maximum separation where trips occurred.

[4] Geometric Mean = $(\ln ATL)(0.11ATL + 2.1 + e^{-ATL})$.

TABLE 8

COMPARISON OF HOME BASED NONWORK THEORETICAL TLFD's
WITH OBSERVED TLFD

Urban Area	Max Obs	Sep Est	One Parameter Gamma R	One Parameter Gamma R^2	One Parameter Gamma RMS Error	Two Parameter** R	Two Parameter** R^2	Two Parameter** RMS Error
*Abilene	24	26	0.9343	0.9688	0.92%	0.9622	0.9259	1.61%
*Amarillo	51	41	0.9802	0.9609	0.66%	0.9912	0.9826	0.47%
*Austin	36	32	0.9780	0.9566	0.78%	0.9779	0.9564	0.79%
Brownsville	31	25	0.9951	0.9901	0.47%	0.9944	0.9886	0.51%
Bryan-College Station	36	37	0.9888	0.9777	0.60%	0.9900	0.9801	0.62%
*Dallas-Fort Worth	94	96	0.8579	0.7359	1.23%	0.9021	0.8139	1.13%
*El Paso	72	67	0.8891	0.7906	1.09%	0.9750	0.9507	0.54%
*Harlingen-San Benito	25	24	0.9700	0.9410	1.29%	0.9460	0.8950	1.89%
*Laredo	14	15	0.9921	0.9843	0.84%	0.9476	0.9362	1.96%
*Lubbock	27	25	0.9389	0.8816	1.44%	0.8385	0.8808	1.44%
McAllen-Pharr	18	19	0.9979	0.9958	0.38%	0.9851	0.9705	1.17%
San Angelo	17	17	0.9822	0.9647	1.12%	0.9594	0.9205	1.85%
*San Antonio	54	59	0.9022	0.8140	1.12%	0.9699	0.9407	0.66%
*Texarkana	21	21	0.9728	0.9463	1.28%	0.9507	0.9039	1.88%
*Tyler	21	18	0.9929	0.9859	0.68%	0.9866	0.9735	0.98%
Victoria	27	28	0.9883	0.9766	0.76%	0.9765	0.9536	1.19%
*Waco	45	40	0.9153	0.8377	1.39%	0.9484	0.8995	1.09%
*Wichita Falls	29	26	0.9829	0.9661	0.79%	0.9925	0.9851	0.51%

*Urban areas used for calibration.

Max Sep — the maximum separation at which an interchange of trips may be expected to occur.

Obs - observed data

Est - estimated data

**Geometric Mean = $(\ln ATL)(0.11ATL + 2.1 + e^{-ATL})$.

TABLE 9

NONHOME BASED

AVERAGE TRIP LENGTH (ATL) DIFFERENCE[1]

Urban Area[2]	Observed ATL	One-Parameter Gamma ATL Difference	Two-Parameter[3] Gamma ATL Difference
1. Laredo	3.908	0.019	0.003
2. Harlingen-San Benito	3.991	0.029	0.000
3. Texarkana	4.343	0.024	0.003
4. Abilene	4.489	0.024	0.003
5. Tyler	4.543	0.012	0.003
6. Wichita Falls	5.946	0.009	0.015
7. Austin	6.329	0.013	0.022
8. Lubbock	6.641	0.016	0.036
9. Amarillo	6.729	0.012	0.034
10. Waco	6.905	0.012	0.038
11. El Paso	8.814	0.008	0.068
12. Dallas-Fort Worth	8.979	0.008	0.075
13. San Antonio	9.576	0.007	0.058
14. McAllen-Pharr	3.898	0.0296	0.009
15. Victoria	4.037	0.0287	0.001
16. San Angelo	4.610	0.0037	0.009
17. Brownsville	4.819	0.0208	0.006
18. Bryan-College Station	5.153	0.0193	0.007

[1] ATL Difference = Observed ATL - Estimated ATL

[2] Urban areas 1-13 used for calibration.

[3] Geometric Mean = $(\ln ATL)(0.11ATL + 2.0 + e^{-ATL})$.

TABLE 10

NONHOME BASED

SUM OF PERCENTAGE TRIPS $\leq$ 3-MINUTES OF SEPARATION

Urban Area[1]	Observed Data Percent	One-Parameter Gamma Percent	Two-Parameter[2] Gamma Percent
1. Laredo	50.06	51.54	49.71
2. Harlingen-San Benito	52.58	50.25	48.33
3. Texarkana	45.30	45.29	43.30
4. Abilene	41.27	43.39	41.53
5. Tyler	42.60	42.72	40.89
6. Wichita Falls	33.57	28.95	29.92
7. Austin	29.75	26.22	28.03
8. Lubbock	21.85	24.28	26.75
9. Amarillo	26.39	23.71	26.38
10. Waco	29.60	22.71	25.72
11. El Paso	23.94	14.76	20.69
12. Dallas-Fort Worth	22.19	14.26	20.37
13. San Antonio	20.26	12.64	19.33
14. McAllen-Pharr	50.30	51.71	49.84
15. Victoria	51.84	49.57	47.64
16. San Angelo	39.65	41.97	40.17
17. Brownsville	37.85	39.44	38.03
18. Bryan-College Station	36.80	35.89	35.13

[1] Urban areas 1-13 used for calibration.

[2] Geometric Mean = $(\ln ATL)(0.11ATL + 2.0 + e^{-ATL})$.

TABLE 11

NONHOME BASED

PERCENTAGE OF TRIPS IN RIGHT TAIL OF DISTRIBUTION[1]

	Urban Area[2]	Observed[3] Maximum Separation	Observed Percent	One-Parameter Gamma Percent	Two-Parameter[4] Gamma Percent
1.	Laredo	17	0.72	1.91	0.97
2.	Harlingen-San Benito	24	0.45	0.27	0.09
3.	Texarkana	21	0.74	0.81	0.44
4.	Abilene	26	0.26	0.25	0.12
5.	Tyler	22	0.67	1.08	0.68
6.	Wichita Falls	28	1.41	1.14	1.33
7.	Austin	31	1.39	0.86	1.17
8.	Lubbock	27	1.28	2.77	3.62
9.	Amarillo	44	0.71	0.14	0.27
10.	Waco	45	0.73	0.13	0.27
11.	El Paso	60	0.33	0.09	0.37
12.	Dallas-Fort Worth	95	0.25	0.00	0.01
13.	San Antonio	52	0.50	0.56	1.59
14.	McAllen-Pharr	16	2.44	1.86	0.96
15.	Victoria	27	0.38	0.10	0.03
16.	San Angelo	17	3.12	4.23	3.45
17.	Brownsville	30	0.73	0.18	0.11
18.	Bryan-College Station	33	0.65	0.13	0.09

[1] Right tail of distribution = the percentage of trips at and beyond 0.60 X observed maximum separation where trips occurred.

[2] Urban areas 1-13 used for calibration.

[3] Observed Maximum Separation — observed maximum separation where trips occurred.

[4] Geometric Mean = $(\ln ATL)(0.11ATL + 2.0 + e^{-ATL})$.

TABLE 12

COMPARISON OF NONHOME BASED THEORETICAL TLFD's
WITH OBSERVED TLFD

Urban Area	Max Sep Obs	Max Sep Est	One Parameter Gamma R	One Parameter Gamma R^2	One Parameter Gamma RMS Error	Two Parameter Gamma** R	Two Parameter Gamma** R^2	Two Parameter Gamma** RMS Error
*Abilene	26	37	0.9861	0.9723	0.86%	0.9763	0.9532	1.21$
*Amarillo	44	48	0.9838	0.9678	0.60%	0.9892	0.9785	0.50%
*Austin	31	37	0.9862	0.9726	0.63%	0.9938	0.9876	0.43%
Brownsville	30	29	0.9808	0.9620	0.98%	0.9771	0.9547	1.11%
Bryan-College Station	33	42	0.9906	0.9813	0.57%	0.9878	0.9758	0.69%
*Dallas-Fort Worth	108	110	0.9162	0.8394	0.83%	0.9568	0.9154	0.63%
*El Paso	60	77	0.9195	0.8455	0.94%	0.9737	0.9480	0.55%
*Harlingen-San Benito	24	27	0.9874	0.9749	0.91%	0.9539	0.9098	1.90%
*Laredo	17	17	0.9759	0.9525	1.47%	0.9393	0.8822	1.52%
*Lubbock	25	28	0.9694	0.9397	0.96%	0.9611	0.0238	1.08%
McAllen-Pharr	16	22	0.9946	0.9893	0.65%	0.9779	0.9563	1.46%
San Angelo	17	19	0.9810	0.9623	1.11%	0.9705	0.9419	1.46%
*San Antonio	52	68	0.9466	0.8961	0.76%	0.9897	0.9795	0.33%
*Texarkana	21	24	0.9839	0.9680	1.02%	0.9575	0.9168	1.76%
*Tyler	22	20	0.9826	0.9655	1.06%	0.9648	0.9309	1.57%
Victoria	27	32	0.9911	0.9823	0.73%	0.9675	0.9361	1.49%
*Waco	45	46	0.9403	0.8842	1.14%	0.9629	0.9273	0.92%
*Wichita Falls	28	30	0.9432	0.8895	1.40%	0.9493	0.9012	1.35%

*Urban areas used for calibration.

Max Sep — the maximum separation at which an interchange of trips may be expected to occur.

Obs - observed data

Est - estimated data

** Geometric Mean = $(\ln ATL)(0.11ATL + 2.0 + e^{-ATL})$.

TABLE 13

TRUCK AND TAXI

AVERAGE TRIP LENGTH (ATL) DIFFERENCE[1]

Urban Area[2]	Observed ATL	One-Parameter Gamma ATL Difference	Two-Parameter[3] Gamma ATL Difference
1. Laredo	3.045	0.095	0.002
2. Texarkana	4.853	0.095	0.003
3. Tyler	4.989	0.038	0.006
4. Abilene	5.007	0.108	0.013
5. Harlingen-San Benito	5.503	0.080	0.016
6. Wichita Falls	6.063	0.072	0.023
7. Lubbock	6.904	0.012	0.051
8. Austin	7.194	0.063	0.041
9. Amarillo	7.564	0.079	0.067
10. Waco	7.948	0.069	0.069
11. El Paso	8.403	0.077	0.012
12. Dallas-Fort Worth	9.503	0.070	0.138
13. San Antonio	9.899	0.066	0.072
14. McAllen-Pharr	4.813	0.082	0.013
15. San Angelo	5.002	0.013	0.017
16. Victoria	5.033	0.109	0.008
17. Brownsville	5.829	0.077	0.017
18. Bryan-College Station	6.259	0.094	0.030

[1] ATL Difference = Observed ATL - Estimated ATL .

[2] Urban areas 1-13 used for calibration.

[3] Geometric Mean = $(\ln ATL)(0.085ATL + 2.1 + e^{-ATL})$.

TABLE 14

TRUCK AND TAXI

SUM OF PERCENTAGE TRIPS ≤ 3-MINUTES OF SEPARATION

	Urban Area[1]	Observed Data Percent	One-Parameter Gamma Percent	Two-Parameter[2] Gamma Percent
1.	Laredo	50.13	52.77	49.04
2.	Texarkana	40.90	42.92	38.22
3.	Tyler	41.60	41.66	37.11
4.	Abilene	41.36	41.41	36.92
5.	Harlingen-San Benito	41.02	37.35	33.45
6.	Wichita Falls	35.01	33.38	30.48
7.	Lubbock	26.19	28.60	27.32
8.	Austin	27.72	27.09	26.31
9.	Amarillo	27.72	25.40	25.28
10.	Waco	28.52	23.83	24.34
11.	El Paso	34.57	22.15	23.52
12.	Dallas-Fort Worth	26.98	18.77	21.43
13.	San Antonio	23.34	17.76	20.86
14.	McAllen-Pharr	42.10	43.25	38.75
15.	San Angelo	37.09	41.74	37.03
16.	Victoria	41.60	41.18	36.75
17.	Brownsville	34.78	34.96	31.64
18.	Bryan-College Station	40.75	32.13	29.62

[1] Urban areas 1-13 used for calibration.

[2] Geometric Mean = $(\ln ATL)(0.085ATL + 2.1 + e^{-ATL})$.

TABLE 15

TRUCK AND TAXI

PERCENTAGE TRIPS IN RIGHT TAIL OF DISTRIBUTION[1]

	Urban Area[2]	Observed[3] Maximum Separation	Observed Percent	One-Parameter Gamma Percent	Two-Parameter[4] Gamma Percent
1.	Laredo	16	1.83	3.54	1.05
2.	Texarkana	20	2.75	4.07	2.12
3.	Tyler	21	1.49	3.32	1.60
4.	Abilene	25	1.24	1.90	0.76
5.	Harlingen-San Benito	25	2.53	2.36	1.69
6.	Wichita Falls	29	2.08	2.60	1.78
7.	Lubbock	28	1.91	4.25	3.66
8.	Austin	35	2.01	2.21	2.02
9.	Amarillo	43	1.42	1.01	1.00
10.	Waco	45	1.55	1.08	1.15
11.	El Paso	54	1.51	0.58	0.67
12.	Dallas-Fort Worth	89	0.33	0.03	0.08
13.	San Antonio	51	1.40	1.64	2.44
14.	McAllen-Pharr	21	2.06	2.88	1.21
15.	San Angelo	18	3.00	5.91	3.80
16.	Victoria	25	1.64	1.94	0.79
17.	Brownsville	27	4.76	2.82	1.83
18.	Bryan-College Station	32	4.14	1.84	1.29

[1] Right tail of distribution = the percentage of trips at and beyond 0.60 X observed maximum separation where trips occurred.

[2] Urban areas 1-13 used for calibration.

[3] Observed Maximum Separation — observed maximum separation where trips occurred.

[4] Geometric Mean = $(\ln ATL)(0.085ATL + 2.1 + e^{-ATL})$.

TABLE 16

COMPARISON OF TRUCK AND TAXI THEORETICAL TLFD's
WITH OBSERVED TLFD

Urban Area	Max Sep Obs	Max Sep Est	One Parameter Gamma R	One Parameter Gamma R^2	One Parameter Gamma RMS Error	Two Parameter Gamma** R	Two Parameter Gamma** R^2	Two Parameter Gamma** RMS Error
*Abilene	25	28	0.9862	0.9725	0.76%	0.9413	0.8861	1.72%
*Amarillo	43	44	0.9801	0.9606	0.59%	0.9774	0.9552	0.67%
*Austin	35	35	0.9661	0.9334	0.86%	0.9574	0.9166	1.00%
Brownsville	27	17	0.9783	0.9571	0.91%	0.9617	0.9248	1.24%
Bryan-College Station	32	40	0.9420	0.8874	1.27%	0.8991	0.8084	1.76%
*Dallas-Fort Worth	89	103	0.8734	0.7629	1.01%	0.9031	0.8156	0.96%
*El Paso	54	72	0.8476	0.7184	1.38%	0.8617	0.7425	1.43%
*Harlingen-San Benito	25	26	0.9828	0.9660	0.83%	0.9473	0.8974	1.51%
*Laredo	16	16	0.9912	0.9825	0.86%	0.9349	0.8739	2.61%
*Lubbock	28	26	0.8334	0.6945	2.07%	0.8991	0.8083	1.64%
McAllen-Pharr	21	21	0.9871	0.9744	0.84%	0.9606	0.9228	1.57%
San Angelo	18	18	0.9686	0.9382	1.27%	0.9568	0.9154	1.58%
*San Antonio	51	63	0.9627	0.9268	0.60%	0.9843	0.9688	0.41%
*Texarkana	20	22	0.9829	0.9660	0.92%	0.9202	0.8467	2.16%
*Tyler	21	19	0.9813	0.9630	0.97%	0.9249	0.8554	2.05%
Victoria	25	30	0.9912	0.9824	0.64%	0.9732	0.9471	1.15%
*Waco	45	43	0.9270	0.8594	1.12%	0.9277	0.8606	1.16%
*Wichita Falls	29	28	0.9508	0.9040	1.24%	0.9082	0.8248	1.77%

*Urban areas used for calibration.

Max Sep — the maximum separation at which at interchange of trips may be expected to occur.

Obs - observed data

Est - estimated data

**Geometric Mean = $(\ln ATL)(0.085ATL + 2.1 + e^{-ATL})$.